



The effect of the air-blowing step on the technique sensitivity of four different adhesive systems

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KEYWORDS

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Summary *Purpose:* To evaluate the technique sensitivity of four different adhesive systems using different air-blowing pressure.

Methods: Four adhesive systems were employed: Clearfil SE Bond [SE] (Kuraray, Japan), G-Bond [GB] (GC Corporation, Japan), Adper Prompt L-Pop [LP] (3M ESPE, USA) and an experimental adhesive, SSB-200 [SSB] (Kuraray, Japan). Twenty-four extracted molars were used. After grinding the coronal enamel surface, the teeth were divided into two equal groups. The first group's teeth were randomly assigned for bonding with the different adhesives using gentle air-blowing (g). For the teeth of the second group, the four adhesive systems were applied using strong air-blowing (s). After storage overnight in 37 °C water, the bonded specimens were sectioned into sticks (1 mm × 1 mm wide), which were subjected to microtensile bond strength testing (μ TBS) at a crosshead speed of 1 mm/min. The load at failure of each specimen was recorded and the data were analyzed by one-way ANOVA and Tukey HSD tests. The surfaces of the fractured specimens were observed using SEM to determine the failure mode.

Results: The results of the μ TBS test showed that the highest bond strengths tended to be with SE for both gentle and strong air-blowing, and the significantly lowest for SSB with strong air streaming. Comparing the two techniques, significant differences were noted only for SSB-200 ($P < 0.05$). For each material, the SEM evaluation did not show distinct differences in the nature of the fractures between the two techniques, except for SSB-200.

Conclusions: The adhesives tested are not technique sensitive, except SSB-200, with regards to the air-blowing step.

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Introduction

Adhesion of resin composite to the tooth substance is required to provide retention, reduce microleakage and improve marginal adaptation. Since its introduction, the enamel etch technique has provided an ideal surface for reliable bonding performance using adhesive resins.¹ However, bonding to dentine has been less reliable due to the characteristics of the dentine substrate, including high organic content,² tubular structure variations,³ the presence of outward fluid movement,⁴ dentine depth,⁵ sclerosis,⁶ and caries.⁷⁻⁹ Bonding of resin composite to dentine is now possible through partial demineralization of the dentine surface, followed by infiltration of the exposed collagen fibrils with hydrophilic resins to obtain the hybrid layer.^{10,11}

Different adhesive systems are commercially available and they can be divided into two broad categories: the systems that use 'total-etching' with 35-40% phosphoric acid, followed by the application of a primer and an adhesive (in one or two different solutions); and the 'self-etching' systems in which the prior etching step is omitted. The self-etching products may have the priming and bonding steps combined (1-step systems) or they may require an additional step (2-step adhesives). For all these systems, adherence to the manufacturer's instructions is implied for successful bonding to dentine. Some researchers have found that errors in application could result in lower bond strengths.¹²

Different authors have investigated the operator variability of these adhesive systems and have found that technique sensitivity is one of the most important variables in the use of these kinds of materials.¹³⁻¹⁵ Frankenberger¹⁶ showed that one of the most critical steps during the application of 'total-etching' systems is the control of the dentine's moisture after the rinsing step. Nowadays, with the introduction of self-etching systems involving better standardized procedures without water rinsing or dentine moisture retention, this problem should theoretically be eliminated.¹⁷ In particular, the newest 'all-in-one' systems should be less technique sensitive due to the reduction of their application to only one step.¹⁸ However, other variables related to their application could perhaps influence the bond strength of these adhesives, such as the air-blowing step. Previous research has reported that manufacturers' instructions are often not strictly adhered to and this may affect the bond strength of the adhesives.¹⁹ Therefore, an adhesive whose bond strength is not heavily reliant on

the technique sensitivity related to its application, may perform better in the clinical situation.

Air-blowing is important to eliminate substances that could influence polymerization and to ensure a good distribution of the adhesive on the dentine surface.²⁰ The duration of air-blowing and the pressure of the air stream are different for each product. It is not known whether deviations from the suggested protocols for air-blowing affect bond strength values.

The purpose of this study was to evaluate the effect of technique sensitivity on μ TBS of four different 'self-etching' (three commercial and one experimental) adhesives, focusing on the air-blowing step. The null hypothesis tested was that μ TBS was not affected by air-blowing.

Materials and methods

Twenty-four non-carious human molars, stored at 4 °C in an aqueous solution of 0.5% chloramine-T, were used for this study according to local institutional guidelines. The occlusal third of the molar crowns was removed by means of an Isomet diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA) to expose the dentine surface. A standard smear layer was produced by treating the surface with 600-grit silicon-carbide paper. All specimens were randomly divided into two groups of 12 teeth each. Four self-etching adhesive systems were employed for this experiment: one 2-step system, SE Bond [SE] (Kuraray Medical Inc., Okayama, Japan) and three all-in-one systems: G-Bond [GB] (GC Corporation, Tokyo, Japan), Adper Prompt L-Pop [LP] (3M ESPE, St Paul, MN, USA), and an experimental adhesive SSB-200 [SSB] (Kuraray Medical Inc., Okayama, Japan). The chemical formulations of the four adhesives are listed in Table 1. The respective manufacturer's instructions for usage of the four adhesives employed are listed in Table 2.

In order to evaluate the technique sensitivity, the teeth of the first group were prepared in accordance with the times suggested by the individual manufacturer's instructions and using gentle air-blowing, while for the teeth of the second group, strong air-blowing was employed. In each case, the air stream was generated by a commercially available canister of compressed contamination-free air for 3 s (EM Clean spray, Nisshin EM Co., Tokyo, Japan) at a distance of 2 cm from the specimen. The strong air stream was at a pressure of 0.68 MPa while the gentle air-blowing occurred approximately at 0.12 MPa. Three teeth

Table 1 Chemical formulations of the four adhesive systems used.

Product name	Manufacturer	Composition
SE bond lot: 011370	Kuraray medical Inc., Okayama, Japan	Primer: 10-MDP, HEMA, hydrophilic dimethacrylate, photoinitiator, water Bond: 10-MDP, Bis-GMA, HEMA, hydrophilic dimethacrylate, microfiller
G-bond lot: 0406161	GC Corporation, Tokyo, Japan	4-MET, phosphate monomer, UDMA, water, acetone, silica filler, photo initiator
Prompt L-Pop lot: 180505	3M ESPE, St Paul, MN, USA	Liquid 1: methacrylated phosphoric esters, Bis-GMA, camphoroquinone, stabilizers Liquid 2: water, HEMA, polyalkenoic acid, stabilizers
SSB-200 lot: 040219	Kuraray medical Inc., Okayama, Japan	10-MDP, HEMA, water, ethanol, dimethacrylate, photoinitiator, filler

per adhesive per technique were prepared. All procedures were carried out by one operator. All surfaces were built-up with resin composite (Clearfil AP-X, Kuraray Medical Inc., Okayama, Japan) in increments to a height of 5 mm. Each incremental layer was light cured for 40 s. After 24 h storage in water at 37 °C, approximately six sticks (1 mm × 1 mm wide) were obtained from each sample using an Isomet diamond saw. Specimens were then fixed to a Ciucchi's jig²¹ with cyanoacrylate glue (Model Repair II Blue, Dentsply-Sankin, Otahara, Japan) and subjected to a tensile force at a crosshead speed of 1 mm/min in a desktop testing apparatus (EZ test, Shimadzu, Kyoto, Japan) until failure occurred. The μ TBS was expressed in MPa, dividing the applied force (N) at

the time of fracture by the bonded area (mm²). Data were evaluated with one-way ANOVA to detect any statistical differences. The Tukey HSD test was used to analyze differences between the two techniques at a significance level of $P=0.05$.

Both halves of the fractured specimens were observed using an optical light microscope (LG-PS2, Olympus Co., Tokyo, Japan) at X20 magnification, and then sputter coated before being observed in a FE-SEM (S-4000, Hitachi, Tokyo, Japan) at an accelerating voltage of 10 kV, to determine the failure mode. All observations were conducted by one person.

Results

Microtensile bond strength test

A total of 137 specimens from 24 teeth were available for microtensile testing. There were

Table 2 Manufacturers' instructions for the four adhesive systems.

Adhesive	Manufacturer's instructions
SE bond	Apply the primer for 20 s Gentle air-blowing Apply the adhesive for 10 s Gentle air-blowing Light cure for 10 s
G-bond	Apply the adhesive for 10 s Strong air-blowing Light cure for 10 s
Prompt L-Pop	Activate the blister Apply the adhesive massaging for 15 s Gentle air-blowing Apply a second coat without massaging Gentle air-blowing Light cure for 10 s
SSB-200	Apply the adhesive for 20 s Gentle air-blowing Light cure for 10 s

Only for G-Bond, the manufacturer's instructions suggest 'strong air blowing'.

Table 3 Mean μ TBS (MPa) for all specimen groups.

Adhesive	Mean	SD	N	Pretesting failures
SE Bond (g)	74.86 ^a	20.74	19	0
SE Bond (s)	68.59 ^{a,b}	14.90	16	0
G-Bond (g)	44.60 ^{c,d}	11.13	20	0
G-Bond (s)	48.77 ^c	12.21	18	0
Prompt L-Pop (g)	43.92 ^{c,d}	16.96	16	0
Prompt L-Pop (s)	31.01 ^d	18.46	20	2
SSB-200 (g)	56.29 ^{b,c,*}	12.35	17	0
SSB-200 (s)	12.32 ^{e,*}	11.83	19	6

g, gentle air; s, strong air. N refers to the total number of specimens including the pretesting failures. *denotes a significant difference between the two groups. The same superscripts denote no statistical difference.

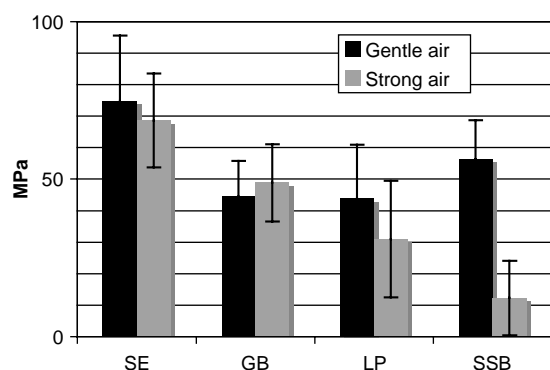


Figure 1 Mean μ TBS and the SDs in MPa of all specimen groups.

pretesting failures in two samples of LP(s) and in six samples of SSB(s). These pretesting failures were considered as 0 MPa and were included in the analysis. The mean μ TBS for the data in MPa are presented in Table 3 and displayed in Fig. 1. Overall, SE tended to have the highest bond strengths for both gentle and strong air-blowing, and the statistically lowest bond strengths were for SSB with strong air streaming ($P < 0.05$).

Statistical analysis using the Tukey HSD test for each material showed a significant difference between the two techniques only for SSB-200.

SEM analysis

The vast majority of the specimens showed visually adhesive failures (at $\times 20$). Observation by SEM at low magnification ($\times 50$) demonstrated the same pattern in all groups. However, at higher magnifications differences began to appear in the mode of failure; the SEM images showed different failure patterns at the interface of the adhesives employed.

The majority of the SE samples, with both gentle and strong air, showed fractures within the adhesive layer (Fig. 2(a)). In the rest of the samples, the fracture occurred primarily within the hybrid layer and the adhesive (Fig. 2(b)).

G-Bond showed fractures at the interface between the dentine and the adhesive as well as cohesive fractures within the adhesive layer in the same sample and this was observed in both groups (Fig. 3(a)). Many 'blisters' were noted in the adhesive layer, irrespective of the technique employed. However, the number ($2.15 \pm 0.34 \mu\text{m}^2$) and size (range: 0.07 – $1.85 \mu\text{m}$) of the 'blisters' were greater in the gentle air-blown specimens compared with those that were subjected to strong air-blowing (number: $1.80 \pm 0.21 \mu\text{m}^2$; size: 0.07 – $1.70 \mu\text{m}$) (Fig. 3(b)).

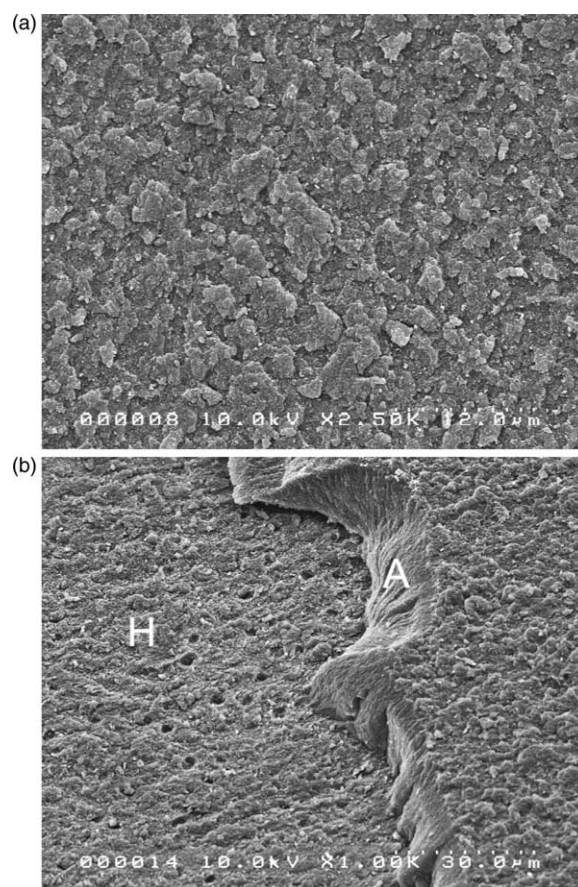


Figure 2 (a) SEM photomicrograph of the fractured surface on the dentine side of a sample of Clearfil SE Bond, typical of both gentle and strong air-blowing procedures. The fracture occurred within the adhesive layer. (b) The fractured surface (dentine side) of Clearfil SE Bond showing the hybrid layer on dentine (H) and the bulk of the adhesive (A).

Prompt L-Pop samples treated with gentle air-blowing showed mixed fractures. Generally, the surfaces presented a portion in which the failure occurred between the dentine and the adhesive layer, and another part with a cohesive fracture within the adhesive (Fig. 4(a)). The majority of the samples prepared with strong air-blowing showed areas with collagen fibrils and resin tags in the tubules while other areas displayed the hybrid layer (Fig. 4(b)).

SSB-200 showed significant morphological differences between the teeth prepared with the two techniques. For the samples treated with gentle air, the fractures occurred between the adhesive layer and the resin composite and/or cohesively within the adhesive (Fig. 5(a)). The teeth prepared with strong air-blowing presented fractures within the adhesive layer only. Higher magnification of the adhesive layer revealed the presence of many voids (Fig. 5(b)).

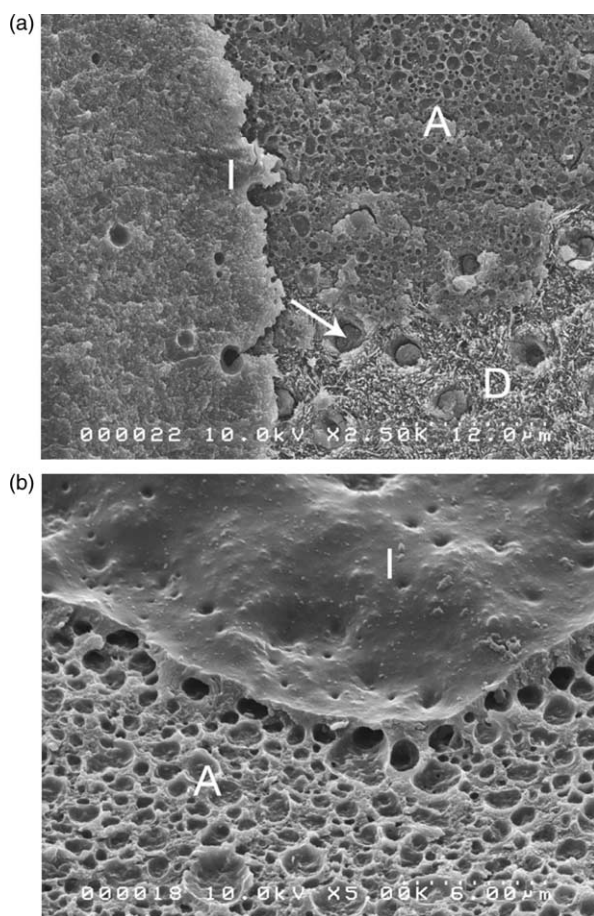


Figure 3 (a) Photomicrograph of fractured surface of G-Bond (strong air) showing the dentine (D), cohesive failure within the adhesive layer (A) and the interface between the adhesive and resin composite (I). Resin tags are present in the tubules (arrowed) and blisters were noted within the adhesive layer. (b) SEM photomicrograph of a G-Bond sample treated with gentle air-blowing showing the presence of blisters within the adhesive. In this particular sample, the failure also occurred at the interface (I) between the adhesive (A) and the resin composite.

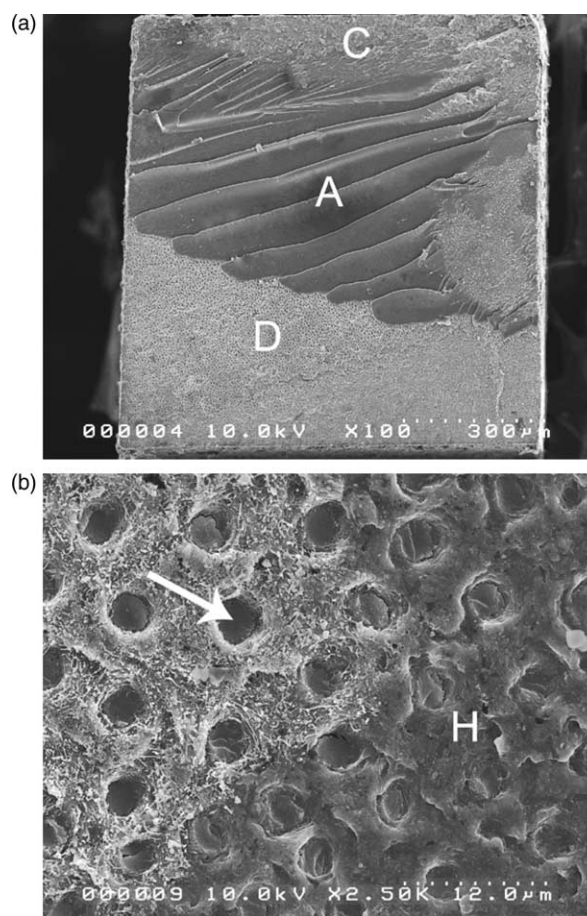


Figure 4 (a) Fractured surface of a Prompt L-Pop sample prepared with gentle air-blowing showing a portion in which the failure occurred between the dentine (D) and the adhesive layer, and another part with a cohesive fracture within the adhesive (A). Remnants of the resin composite (C) are present in this specimen. (b) SEM photomicrograph of a typical Prompt L-Pop specimen prepared with strong air, showing areas with collagen fibrils and resin tags (arrowed) in the tubules while other areas display the hybrid layer (H) on the dentine.

Discussion

Generally, current interest in dentine bonding research is focused on reducing the number of application steps in the bonding procedure and reducing the technique sensitivity as well as operator variability. The all-in-one adhesives have reduced the number of steps involved. There are two kinds of all-in-one systems, the two-bottle adhesives and the one-bottle systems. Prompt L-Pop falls into the category of two-bottle systems while G-Bond and SSB-200 are one-bottle adhesives. In contrast, SE Bond is a two-bottle two-step adhesive. Although the application procedure has

been simplified by the all-in-one adhesives, their technique sensitivity remains unknown.

While Miyazaki et al.²⁰ have shown the importance of the primer application method in the resultant bond strength of adhesives, the specific effect of the air-blowing step on the all-in-one systems has not been previously investigated. This study assessed the effect of gentle air-blowing and strong air on the bond strengths of these systems compared to a two-step adhesive. The two-step system used in this study, SE Bond, has consistently demonstrated high bond strengths in other studies²²⁻²⁴ and hence was used in this investigation.

SE Bond showed the highest bond strengths regardless of gentle and strong air-blowing during

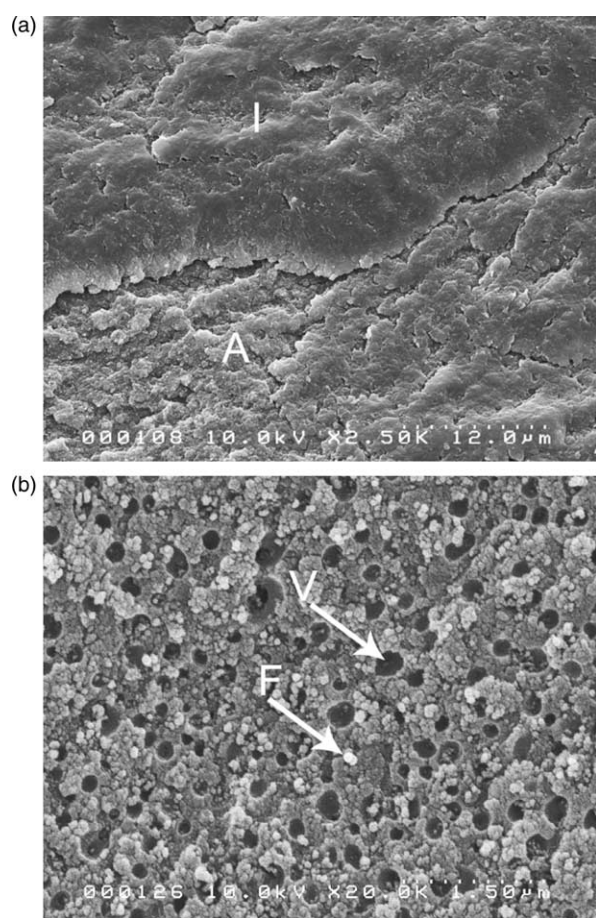


Figure 5 (a) The fractured surface of an SSB-200 specimen (gentle air) showing a part with the fracture at the interface (I) between the adhesive layer and the resin composite and another area with cohesive fracture within the adhesive (A). (b) SEM photomicrograph of a typical SSB-200 sample (strong air) at high magnification showing the presence of voids (V) and fillers (F) within the adhesive.

the application of the primer. The fact that most of the fractures occurred within the adhesive layer suggests that this system is less technique sensitive to the air-blowing step. The bond strengths were not statistically influenced by air-blowing. This is perhaps due to the fact that application of the bonding resin may have compensated for the strong air-blowing. The components of the bonding resin in SE Bond (10-MDP, Bis-GMA and HEMA) may have a good affinity to primed and a strongly air blown dentin surface in the same way as to a gentler blown surface.

Although the instructions for G-Bond state that strong air-blowing is required, this is not borne out by the results of this study in terms of the μ TBS. Moreover, the fracture patterns for both strong and gentle air-blowing were similar. An unique feature noted with this system was the presence of

'blisters' within the adhesive. The number and size of these blisters were greater in the gentle air-blown specimens compared to the strong air-blown samples. An important difference between G-Bond and the other adhesives used was that it does not contain hydrophilic monomers such as HEMA. HEMA is soluble in water, acetone and alcohol.²⁵ HEMA is also an organic material that has an affinity to hydrophobic monomers. Hence, it can be a useful medium for the hydrophilic and hydrophobic components. On the other hand, HEMA creates a hydrogel within the hybrid layer and adhesive resin in some cases.²⁶ The hydrogel may provide a channel for water permeation that has the potential to affect the durability of bonds, especially when poly-HEMAs of low molecular weight are created.

G-Bond contains acetone as a solvent. However, as it does not contain HEMA, it is speculated that evaporation of the acetone in G-Bond could result in phase separation of the components. This may be the reason for the blister formation noted in this adhesive. Furthermore, the blisters were greater in the samples that were subjected to gentle air-blowing. While strong air-blowing may prevent pooling of the adhesive on the substrate surface, gentle air-blowing may encourage pooling. The combination of evaporation of acetone and pooling may result in greater phase separation. Phase separation has been reported by other researchers²⁷ as has blister formation.²⁶ The long-term effects of this are unknown.

It is not apparent as to why there was no difference between strong and gentle air-blowing with G-Bond. Blister formation in gentle air-blown samples appeared greater in number and the bond strengths were lower than in gentle air-blowing. This may be because the large numbers of defects could have acted as the origins of the fractures. However, the mechanical properties of the cured resin in both groups may have been similar which led to no statistical difference in the results. Further, TEM observation and mechanical testing of the adhesive resin are needed for future work.

Prompt L-Pop did not show significant differences in μ TBS between the gentle and strong air-blown samples. However, pretesting failures occurred in the strong air-blown group. SEM examination of the samples in both groups showed differences in the fractured surface. The typical fracture pattern in the gentle air-blown group was mixed, while strong air-blowing resulted in interfacial failure. This latter type of failure is usually suggestive of a weak bond between the adhesive and the substrate. This is probably also the reason for the pretesting failures obtained in the strong

air-blowing group. Strong air-blowing may have caused over-removal of the adhesive resin causing incomplete enveloping of the collagen fibrils (Fig. 4(b)) leading to early failure in some samples and adhesive failure during testing in others. The lack of statistical difference between the two groups may be partly due to the large standard deviation of the data in both groups. However, the bond strength of strong air-blown samples tended to be lower compared to the gentle air-blown group.

The experimental adhesive, SSB-200, showed significantly lower bond strengths in the strong air-blown group than the gentle air group. The strong air group demonstrated the lowest bond strengths in the study. In addition, several pretesting failures were noted in the strong air group. These differences between both groups were confirmed by the morphological findings. The gentle air-blown group showed more complex failures (at different planes), while those in the strong air group consistently failed within the adhesive. Fig. 5(b) shows the presence of many voids in the adhesive. The authors speculate that these voids are pockets of air, which could be stress raisers within the cured adhesive resin during testing. This may be a big reason for the poor adhesion in this group. It is speculated that when strong air-blowing is used, water and solvents are evaporated quickly resulting in a viscous resinous material with entrapped air bubbles, remaining on the dentin surface. This would lead to weaker mechanical properties, resulting in lower bond strengths.

Since the introduction of self-etching primers, gentle air-blowing was generally required for removing the excess primer solution. It is commonly recommended by the manufacturers that gentle blowing should be performed in order to achieve higher bond strengths. However, the instructions for G-Bond represent a departure from the usual protocol. In spite of this, there was still the presence of blisters within the adhesive. Clinicians are usually accustomed to gentle air-blowing when using the self-etching systems. Gentle air-blowing reduces the possibility of dispersal of the components of the adhesive into or out of the oral environment. This is particularly important as many adhesives contain HEMA and organic components. In this study, strong air-blowing did not improve the bond strengths of the adhesives tested; in fact, this had an adverse effect on one of them (SSB-200). It also resulted in pretesting failures in two of the adhesives (LP and SSB). Hence, the use of strong air-blowing with these adhesives is not recommended.

The null hypothesis that μ TBS was not affected by air-blowing was accepted for SE Bond, G-Bond

and Prompt L-Pop, but rejected in the case of SSB-200. However, pretesting failures were observed in the Prompt L-Pop and SSB-200 groups. In conclusion, the adhesives used were not technique sensitive in terms of the air-blowing step, except for Prompt L-Pop and the experimental adhesive, SSB-200.

References

1. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. *Journal of Dental Research* 1955;34:849-53.
2. Eick JD, Cobb CM, Chappel P, Spencer P, Robinson SJ. The dentinal surface: its influence on dentinal adhesion. Part I. *Quintessence International* 1991;22:967-77.
3. Eliades G. Clinical relevance of the formulation and testing of dentine bonding systems. *Journal of Dentistry* 1994;22:73-81.
4. Perdigao J. *An ultra-morphological study of human dentine exposed to adhesive systems*. PhD thesis. Leuven, Belgium: Van Der Poorten; 1995.
5. Tao L, Pashley DH. Shear bond strengths to dentine: effects of surface treatments, depth and position. *Dental Materials* 1988;4:371-8.
6. Kwong SM, Cheung GSP, Kei LH, Itthagarun A, Smales RJ, Tay FR, et al. Micro-tensile bond strengths to sclerotic dentine using a self-etching and a total-etching technique. *Dental Materials* 2002;18:359-69.
7. Yoshiyama M, Tay FR, Doi J, Nishitani Y, Yamada T, Itou K, et al. Bonding of self-etch and total-etch adhesives to carious dentine. *Journal of Dental Research* 2002;81:556-60.
8. Sengun A, Unlu N, Ozer F, Urk B. Bond strength of five current adhesives to caries-affected dentine. *Journal of Oral Rehabilitation* 2002;29:777-81.
9. Yoshiyama M, Urayama A, Kimochi T, Matsuo T, Pashley DH. Comparison of conventional vs self-etching adhesive bonds to caries-affected dentine. *Operative Dentistry* 2000;25:163-9.
10. Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. *Journal of Biomedical Materials Research* 1982;16:265-73.
11. Van Meerbeek B, Willems G, Celis JP, Roos JR, Braem M, Lambrechts P, et al. Adhesives and cements to promote preservation dentistry. *Operative Dentistry* 2001;26(Suppl. 6):119-44.
12. Finger WJ, Balkenholm M. Practitioner variability effects on dentine bonding with an acetone-based one-bottle adhesive. *Journal of Adhesive Dentistry* 1999;1:311-4.
13. Sano H, Kanemura N, Burrow MF, Inai N, Yamada T, Tagami J. Effect of operator variability on dentine adhesion: students vs. dentist. *Dental Materials Journal* 1988;17:51-8.
14. Miyazaki M, Onose H, Moore BK. Effect of operator variability on dentine bond strength of two-step bonding systems. *American Journal of Dentistry* 2000;13:101-4.
15. Re D, Augusti D, Spreafico D, Gagliani M. Effect of operator variability on dentine adhesion. *Journal of Dental Research* 2004;83(Spec iss A):1740.

16. Frankenberger R, Kramer N, Petschelt A. Technique sensitivity of dentine bonding: effect of application mistakes on bond strength and marginal adaptation. *Operative Dentistry* 2000;**25**:324-30.
17. Inagaki A, Chigira H, Itho K, Wakumoto S. Effect of self-etching primers on dentine. *Dental Materials* 1989;**5**:403-7.
18. Frey O. Creating a reliable bond. An all-in-one system. *American Journal of Dentistry* 2000;**13**(Spec Iss):85D-87D.
19. Peutzfeldt A, Asmussen E. Adhesive systems: effect on bond strength of incorrect use. *Journal of Adhesive Dentistry* 2002;**4**:233-42.
20. Miyazaki M, Platt JA, Onose H, Moore BK. Influence of dentine primer application methods on dentine bond strength. *Operative Dentistry* 1996;**21**:167-72.
21. Paul SJ, Welter DA, Ghazi M, Pashley DH. Nanoleakage at the dentin adhesive interface vs μ -tensile bond strength. *Operative Dentistry* 1999;**24**:181-8.
22. Sattabanasuk V, Shimada Y, Tagami J. The bond strength to different dentin surface characteristics. *Operative Dentistry* 2004;**29**:333-41.
23. Armstrong SR, Vargas MA, Fang Q, Laffoon JE. Microtensile bond strength of a total-etch 3-step, total etch 2-step, self etch 2-step and a self etch 1-step dentin bonding system through 15-month water storage. *Journal of Adhesive Dentistry* 2003;**5**:47-56.
24. Kaaden C, Powers JM, Friedl K-H, Schmalz G. Bond strength of self-etching adhesives to dental hard tissues. *Clinical Oral Investigation* 2002;**6**:155-60.
25. Nakabayashi N, Pashley DH. *Hybridization of dental hard tissues*. Tokyo: Quintessence Publishing Co. Ltd; 1998. p. 31-2.
26. Tay FR, King NM, Chan KM, Pashley DH. How can nanoleakage occur in self-etching adhesive systems that demineralise and infiltrate simultaneously? *Journal of Adhesive Dentistry* 2002;**4**:255-69.
27. Van Landuyt K, De Munck J, Snauwaert J, Coutino E, Poitevin A, Yoshida Y, et al. Monomer-solvent phase-separation in one-step self-etch adhesives. *Journal of Dental Research* 2005;**84**:183-8.

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